LARP

BNL - FNAL - LBNL - SLAC

LARP BEAM INSTRUMENTATION and RF

A. Ratti

LBNL

Presented at the DoE review of LARP

Fermilab

July 15-16, 2010

LARP

Outline

Experience from beam commissioning

Images from each of the instrument in operation

Lots of hardware pictures shown last year

ALL THE DATA SHOWN TODAY IS FROM LHC

Plans for FY11

Conclusions

Advancing Accelerator Technology

Major contributions to the field:

Benefiting the LHC and US colliders

- The AC dipole concept came from LARPs collaborations
  - now installed in all three hadron colliders
- The luminosity Monitor is designed to survive a level of radiation 100x larger than ever seen before
- Synch light monitoring on proton storage ring – world first – from PEPII experience
- Tune and Coupling feedback is a world first, accomplished in RHIC
- The LHC Schottky monitor lead to the upgrade of the Tevatron system

Graduate students and post-docs actively involved

- 1 PhD on AC Dipole
- 1 PhD on LLRF
- Several student projects in Lumi
  - Best project award at Sep 2009 APS-CA meeting

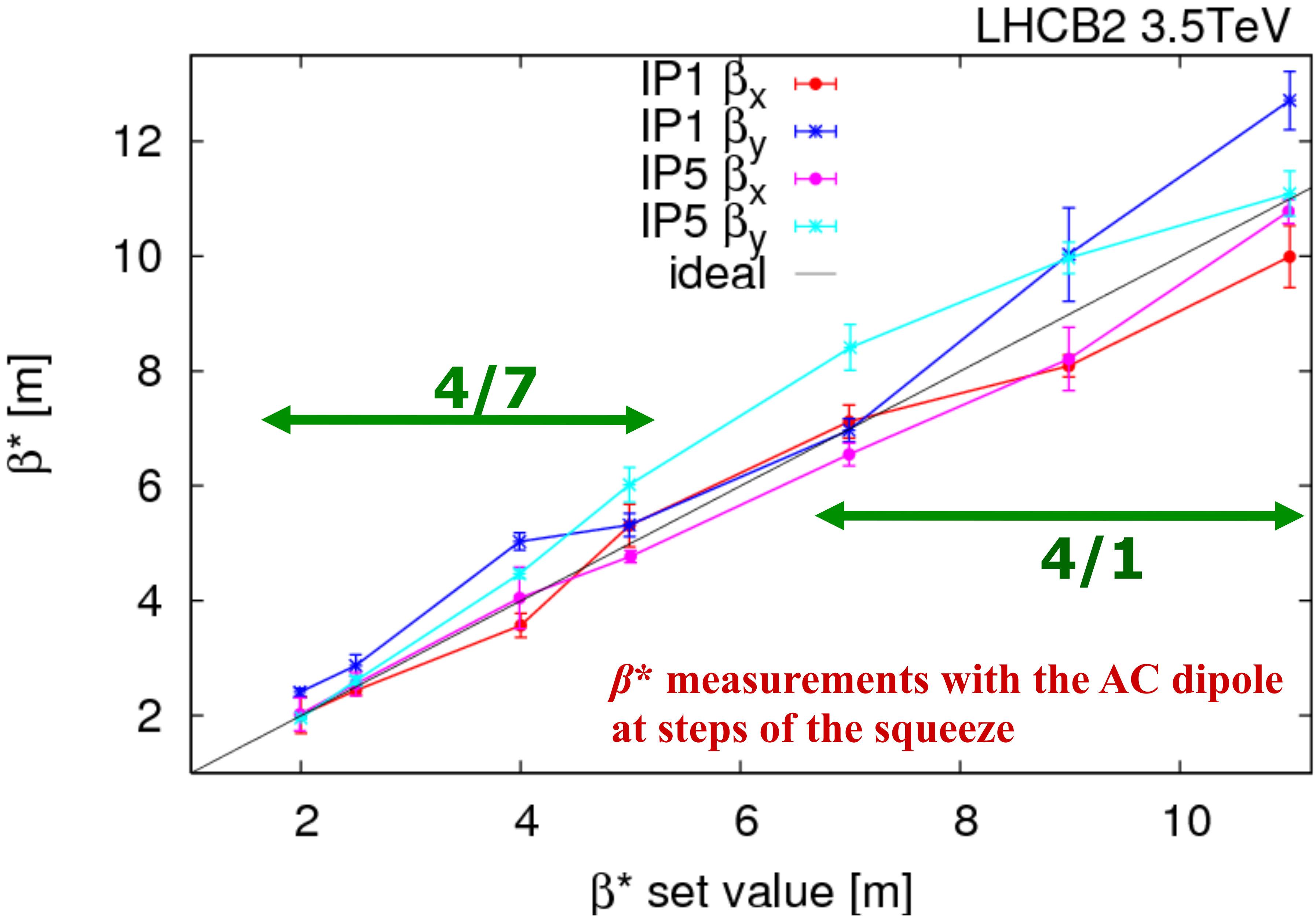
LARP

Success from the Start

With the LHC commissioning LARP's instruments are playing a very important and visible role in the CCC control room.

- AC Dipole
  - Due to the LHC's slow cycle (~1 hr for ramp up, ramp down, squeeze, precycle…), the AC dipole (non destructive) is **the only probe to beam optics above injection** energy
  - ***β*-beating and local coupling** have been measured and corrected for *β*-squeeze with the AC dipole
- Synchrotron light monitors
  - Actively the main **abort gap monitor**
- Schottky monitors
  - First signals with recent increase to nominal bunch charge
- Luminosity monitors
  - Operational since day 1, not yet the baseline instrument
- Tune tracker
  - Essential element during the ramps

β-Squeeze Commissioning for IPs 1&5



Test of Abort-Gap Cleaning

December 16: Injected 4 bunches into Beam 2

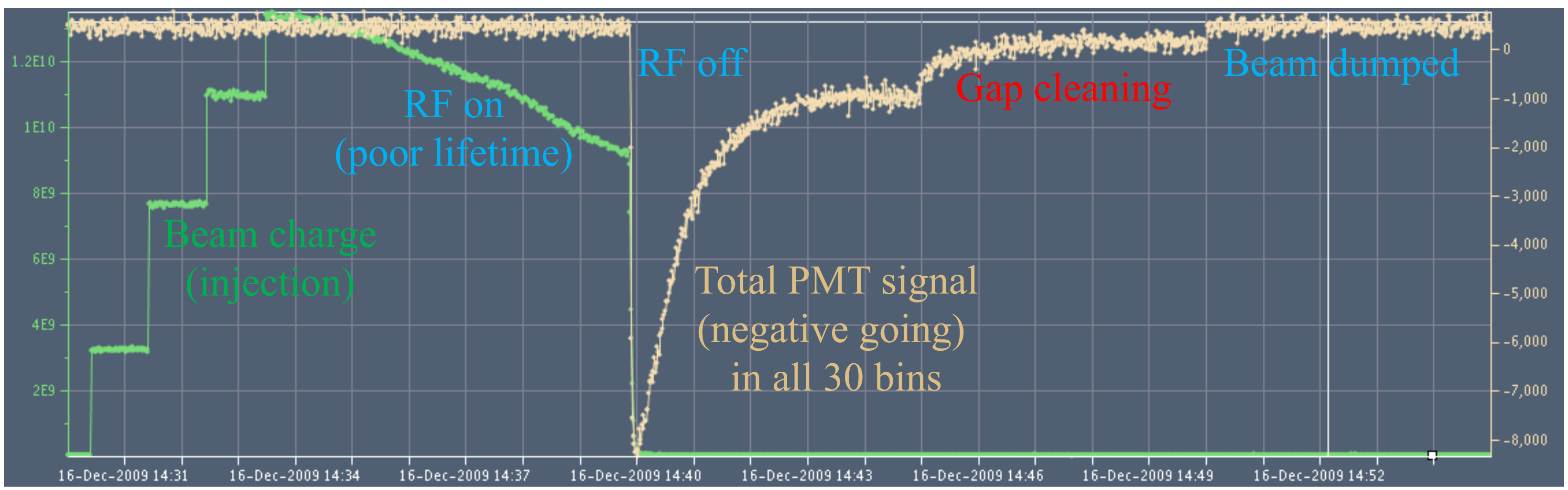
- Poor lifetime, but not important for this experiment

Turned off RF, and coasted for 5 minutes

Abort-gap monitor detected charge drifting into the abort gap

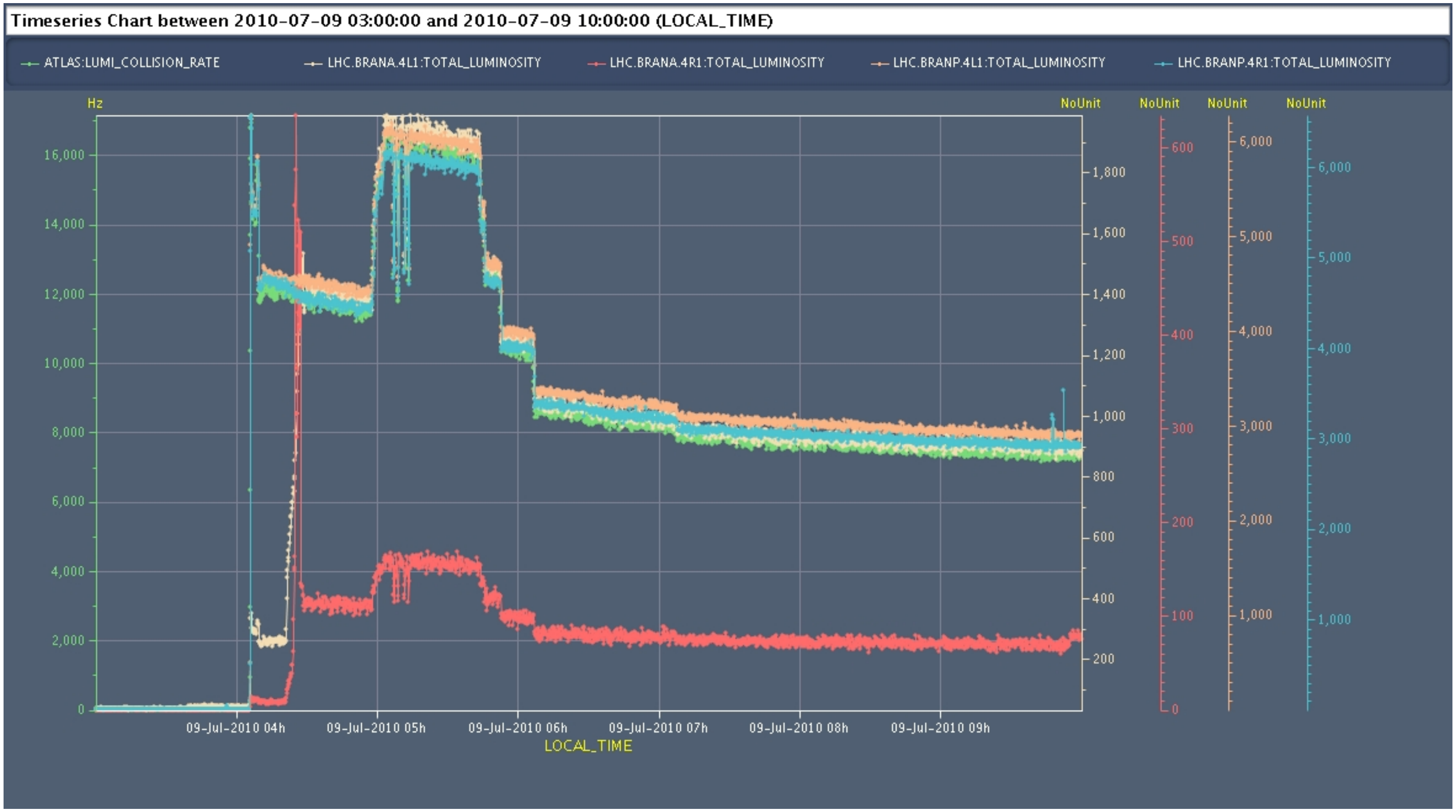
Excited 1 μs of the 3-μs gap at a transverse tune for 5 minutes

- How well did this work? Look inside the gap...

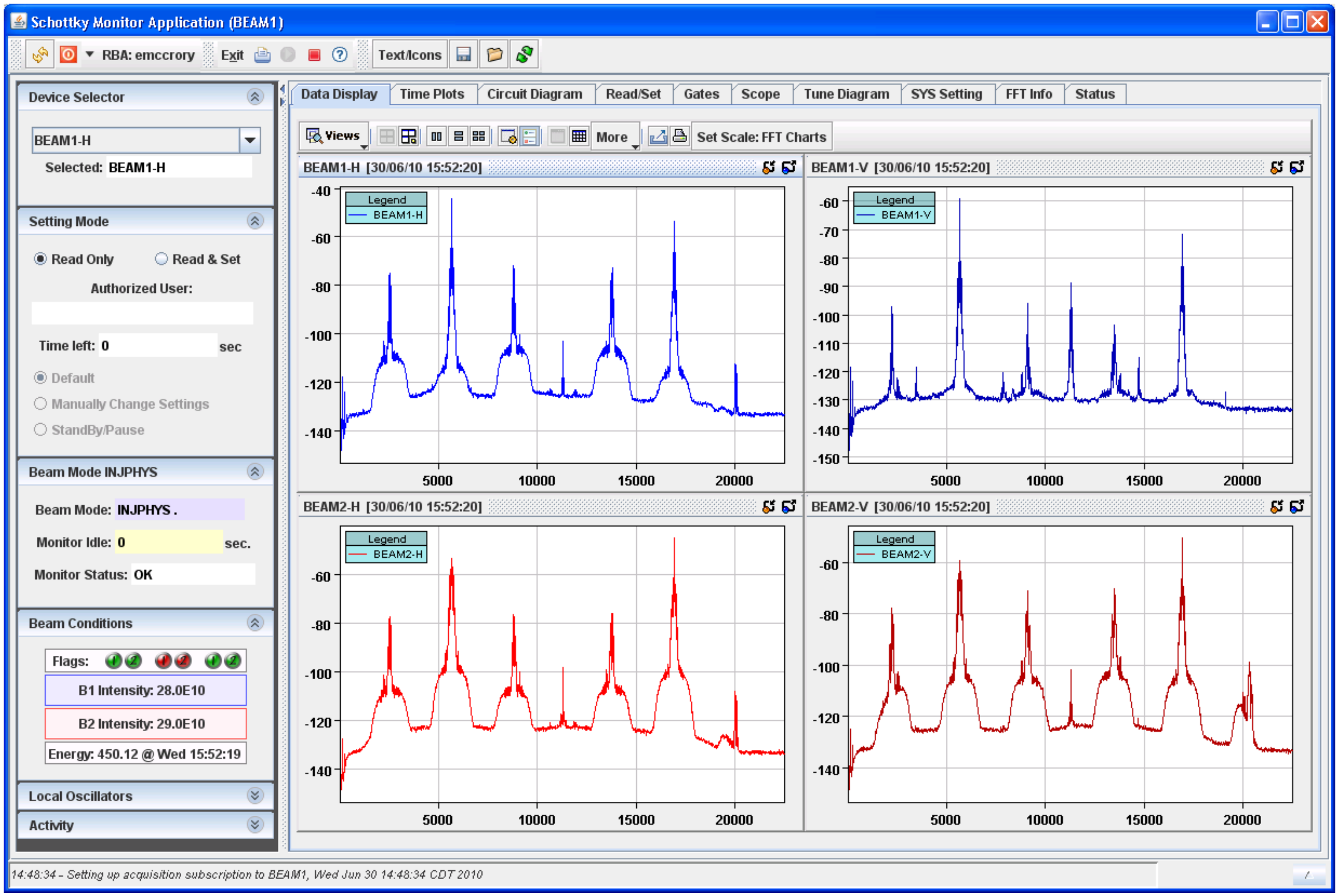


0 25 minutes

Luminosity monitors during one store



First Schottky Signals



June 30, 2010

AC Dipole

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Started in FY07, lead by S. Kopp (UT, Austin)

FNAL graduate student PhD project – now Toohig fellow with support from FNAL scientists

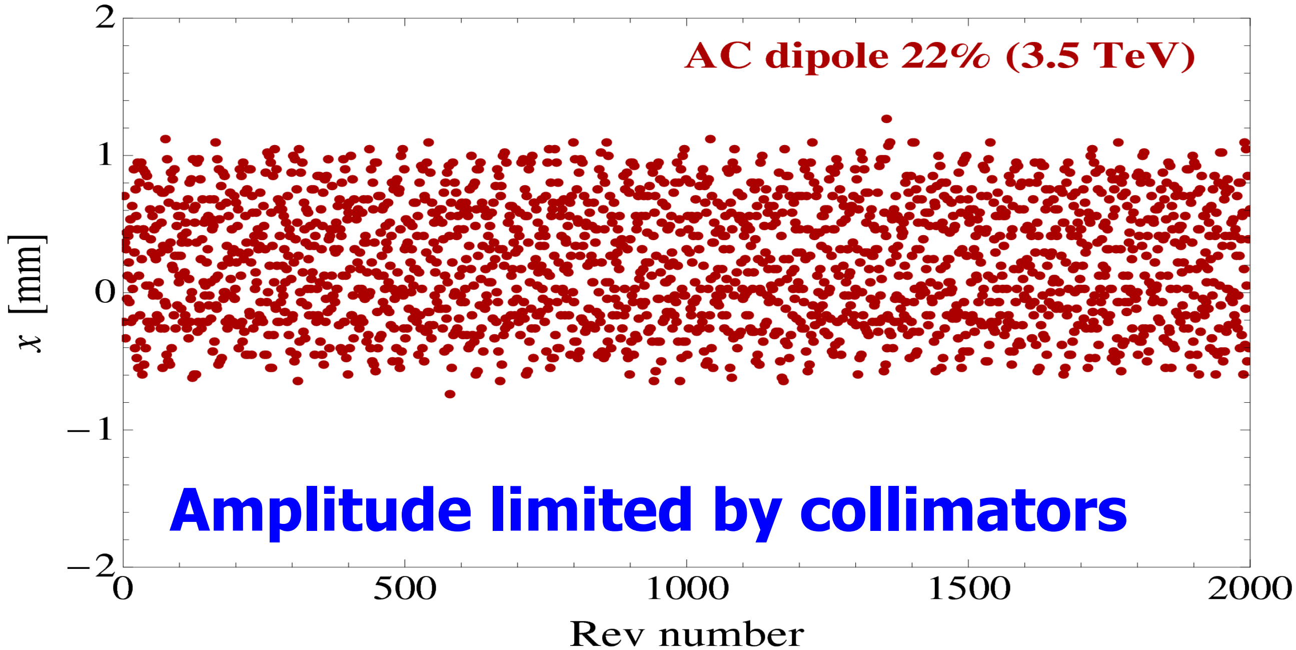
VERY active involvement from BNL, FNAL and CERN

All three labs have developing for AC dipole solution for internal use

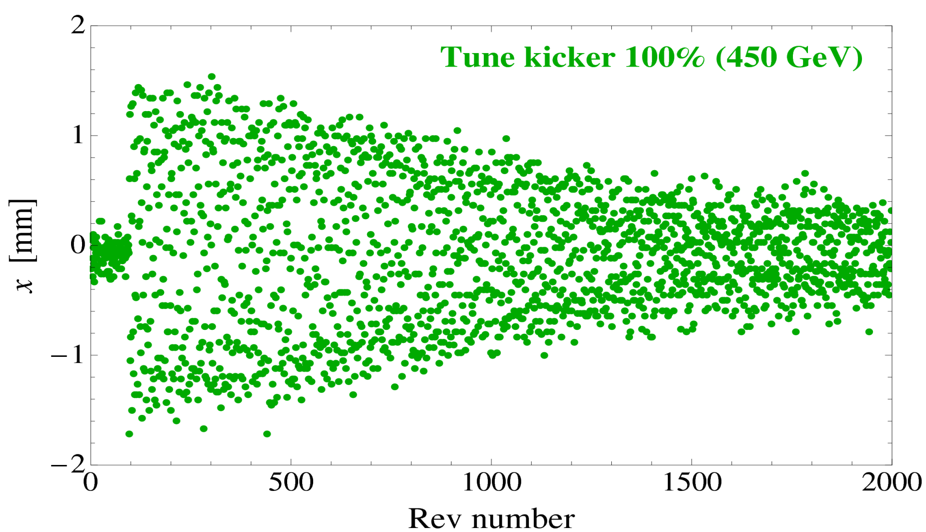
All labs contributing resources to make it happen

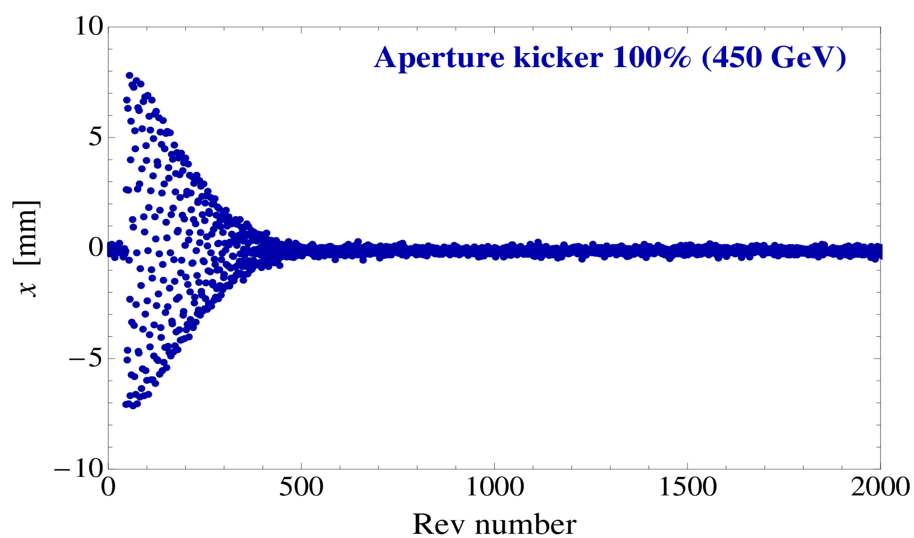
LARP committed to develop concepts on US colliders and provide system description for CERN to implement in LHC

AC dipoles produce clean signals with (almost no) emittance growth.

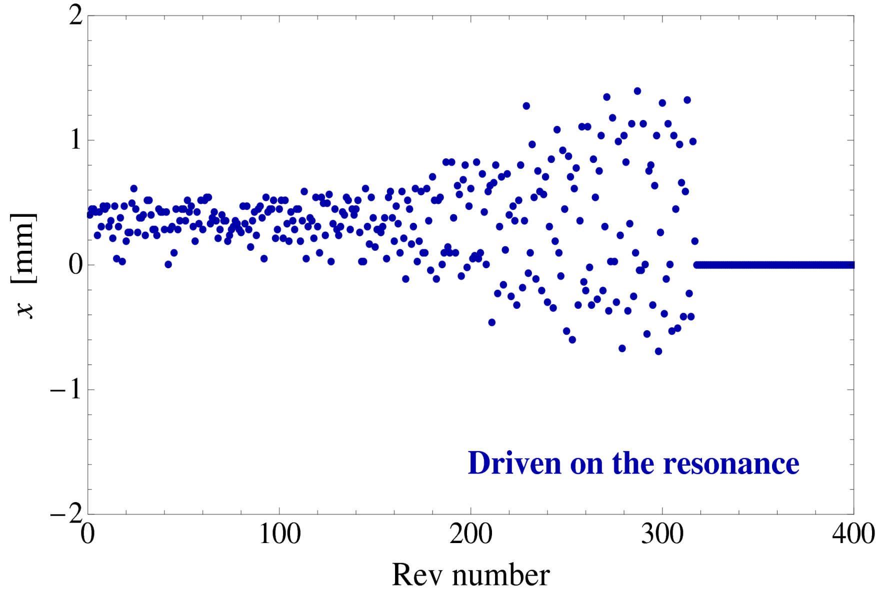


LHC has 4 kickers (HV ×2 beams).
Each can be used as
- **AC dipole**
- **tune kicker**
- **aperture kicker**

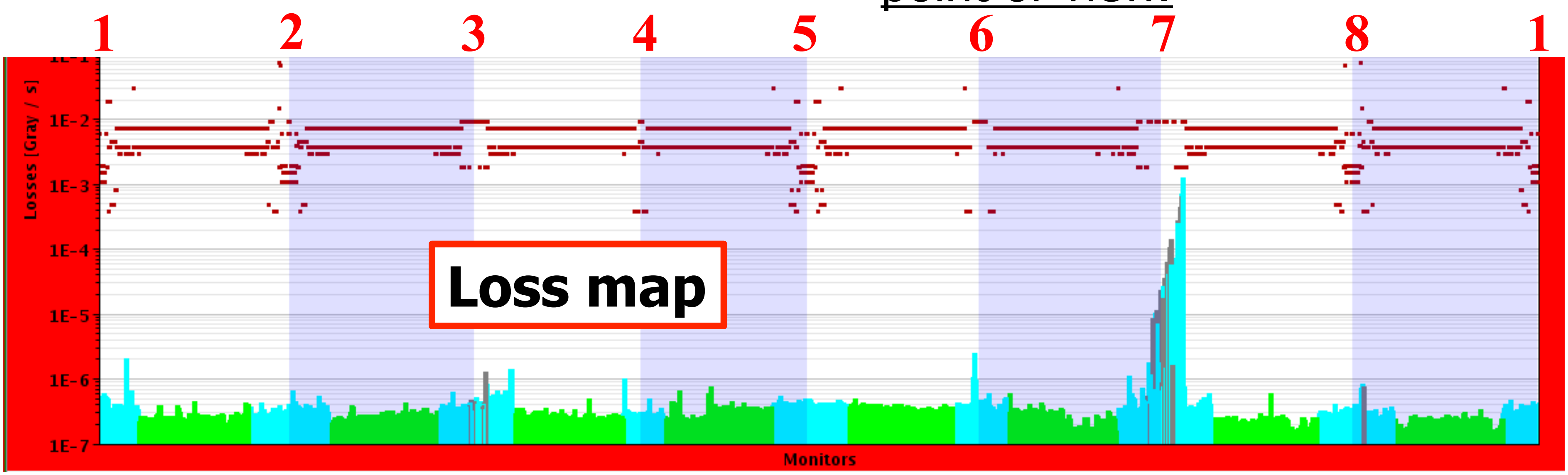




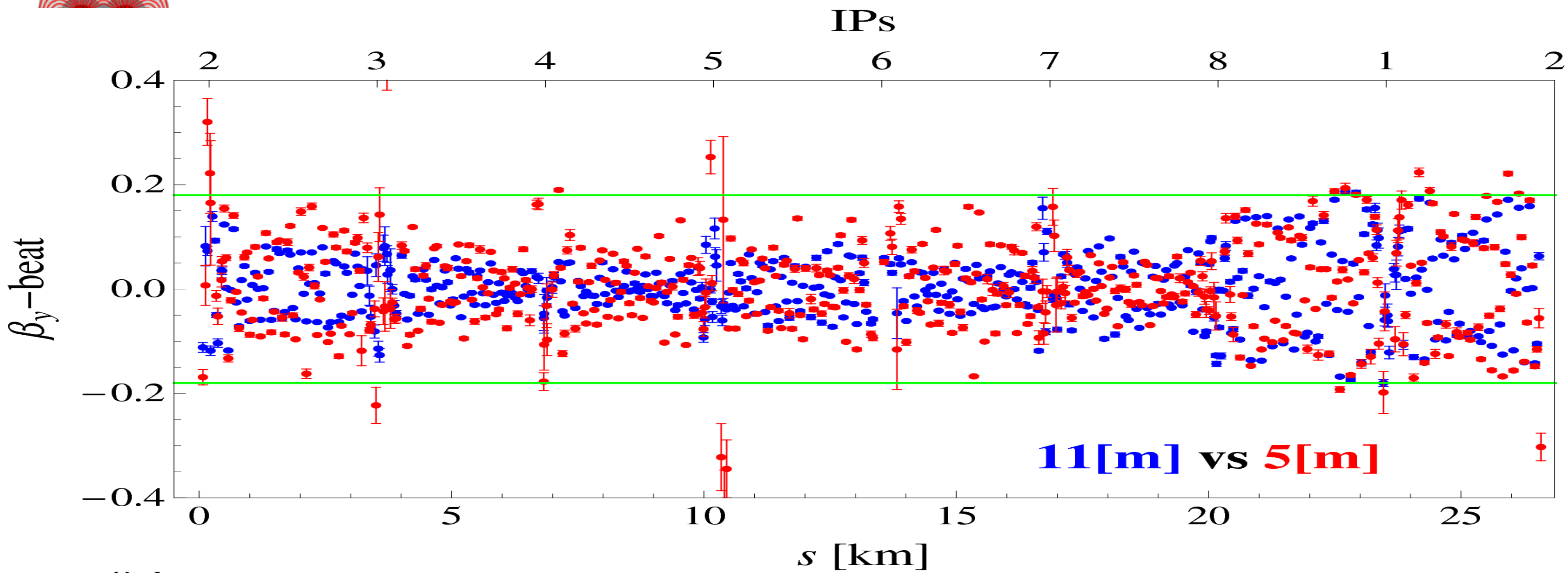
Test of the machine protection system.

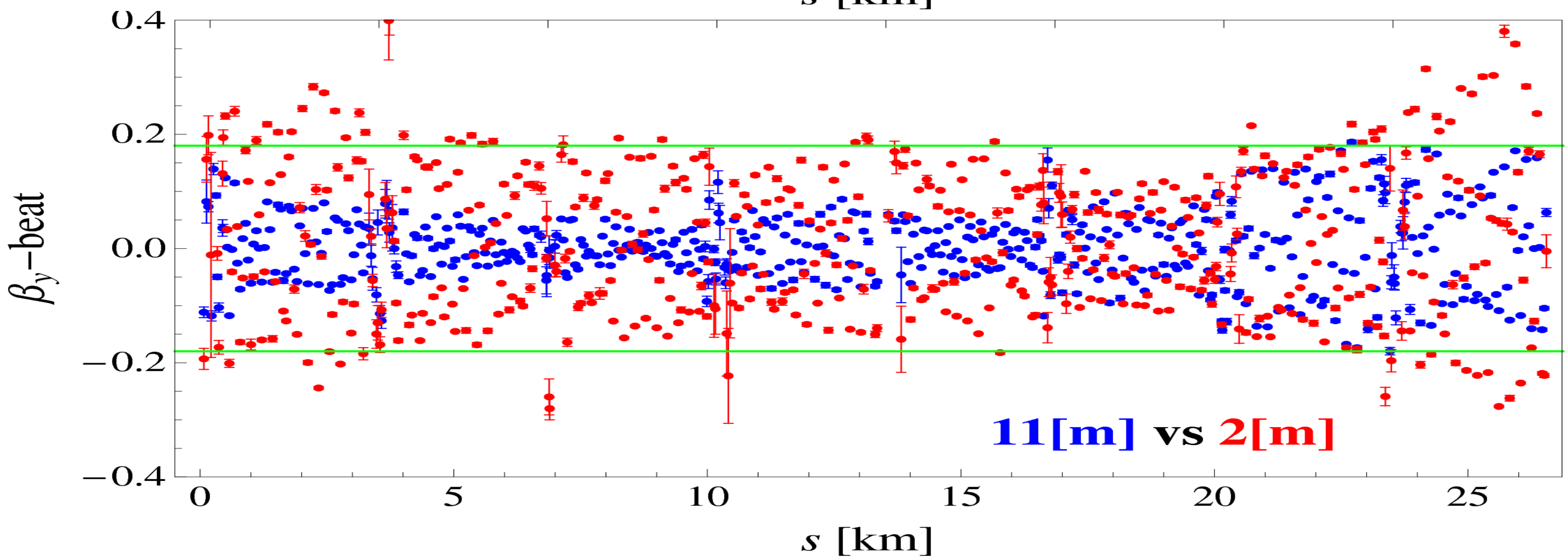


- Assuming the worst case, the beam is driven on the resonance (450 GeV).
- The beam is dumped after ~300 turns (expected).
- Clean dump and losses only at primary collimators.
- <u>The AC dipole is preferred from the machine protection point of view.</u>

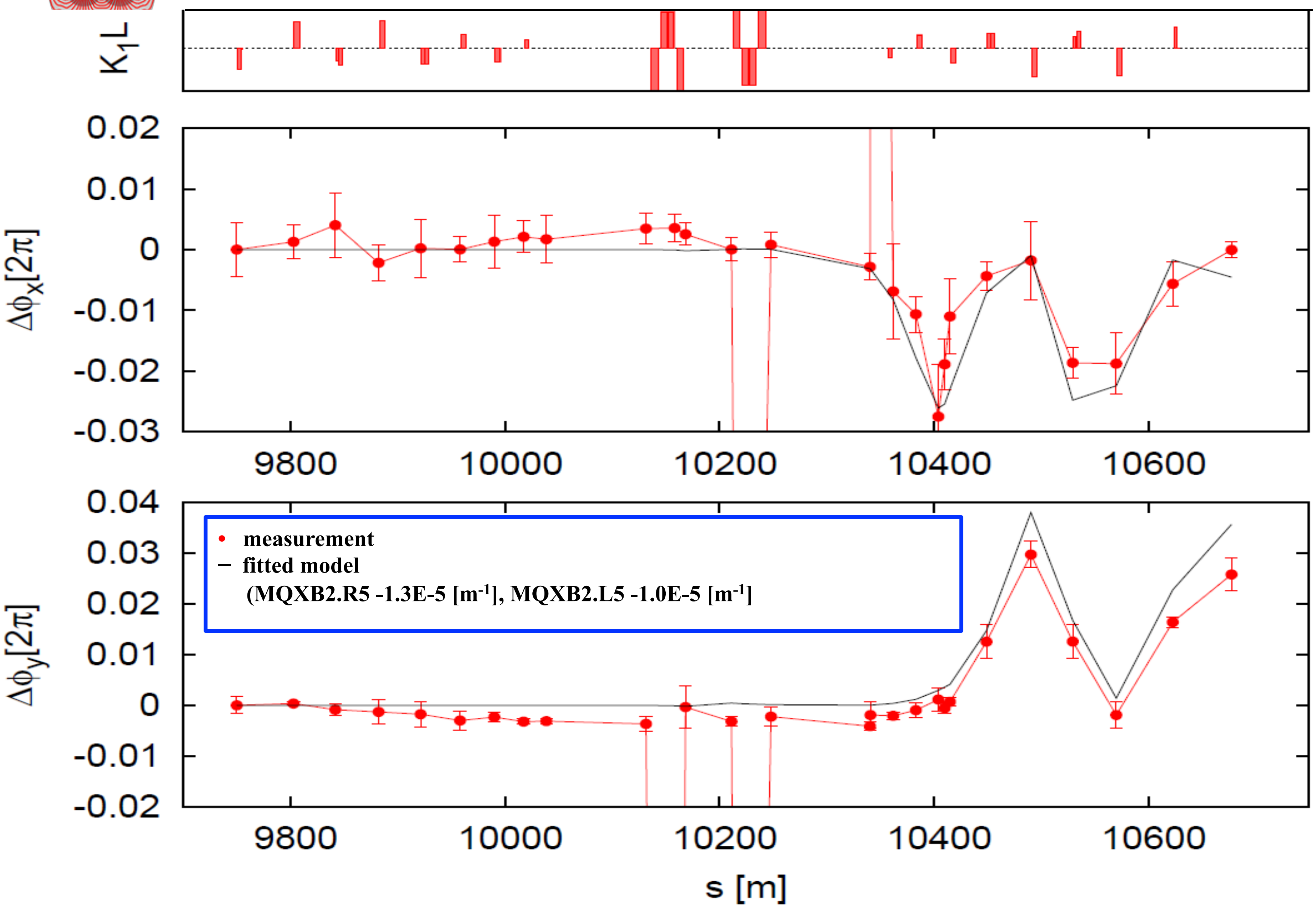


β-beating got larger during the squeeze.





Local correction at IP5 based on phase error



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AC Dipole Summary

The AC Dipole Task has been successfully completed.

- All four AC dipoles are commissioned and in operational.
- Required specifications have been achieved.
- The AC dipoles have been integrated into the operational system and beam optics package.
- The AC dipoles are the primary probe of beam optics above injection.

The next step is that CERN makes good use of them.

- Linear diagnosis has been already established (more of less).
- The next is RDT, detuning…
- Off course, we’re happy to keep in touch.

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Synchrotron-Light Monitors

Two applications:

- BSRT: Imaging telescope, for transverse beam profiles
- BSRA: Abort-gap monitor, to verify that the gap is empty
  - When the kicker fires, particles in the gap get a partial kick and might cause a quench.

Two particle types:

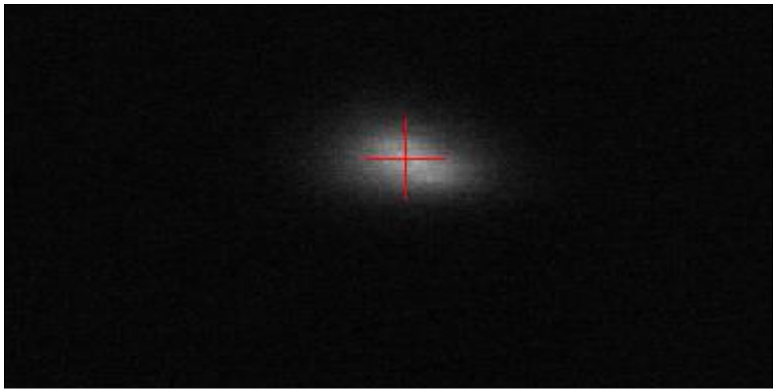
- Protons and lead ions

Three light sources:

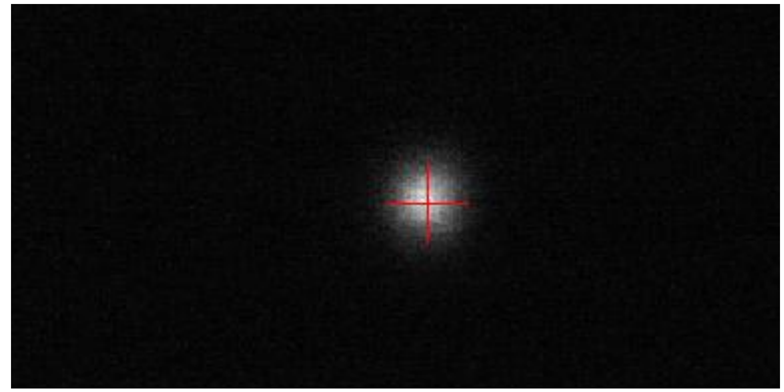
- Undulator radiation at injection (0.45 to 1.2 TeV)
- Dipole edge radiation at intermediate energy (1.2 to 3 TeV)
- Central dipole radiation at collision energy (3 to 7 TeV)
- Spectrum and focus change during ramp

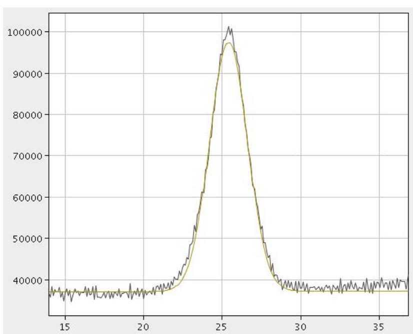
LHC Beams at Injection (450 GeV)

Beam 1



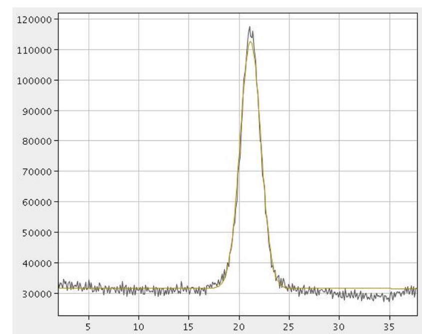
Beam 2

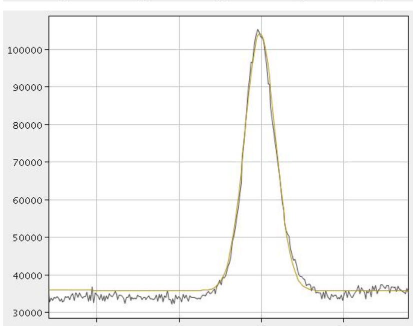




Horizontal

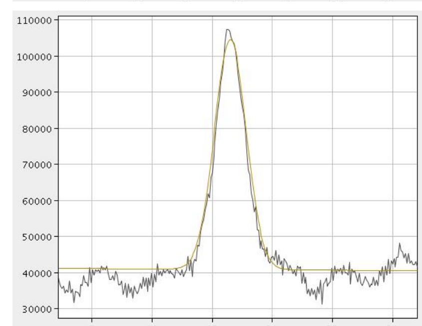
1.3 mm 1.2 mm





Vertical

0.9 mm 1.7 mm



Light from undulator.
No filters. Open slit.

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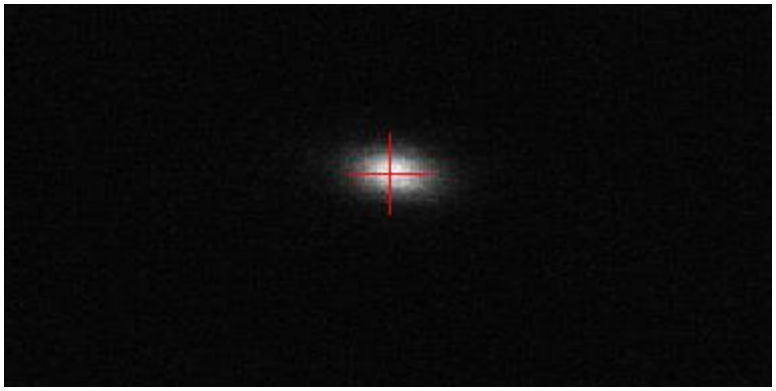
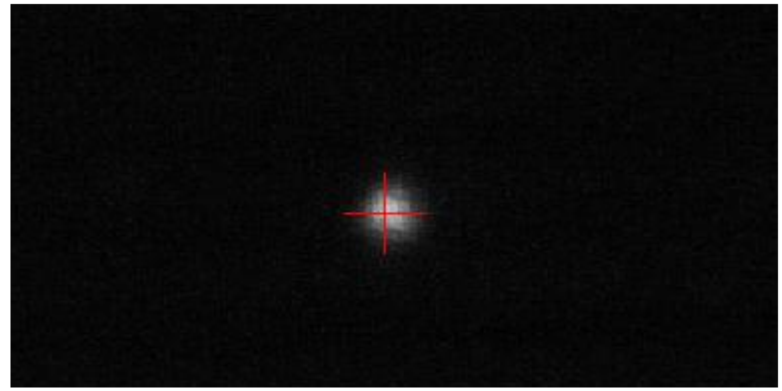
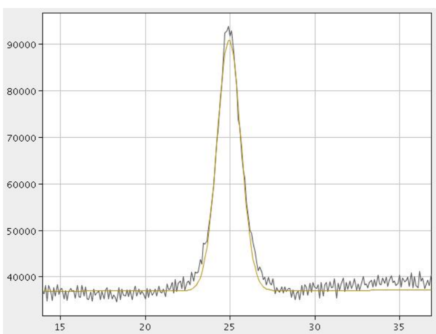
LHC Beams at 3.5 TeV

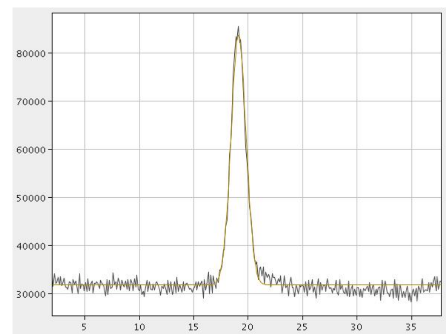
Beam 1



Beam 2

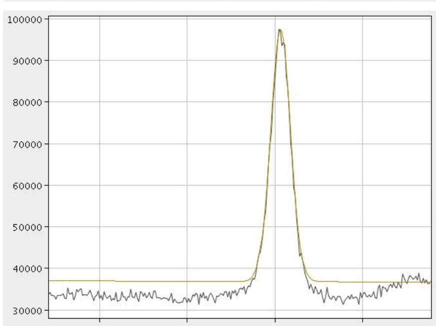


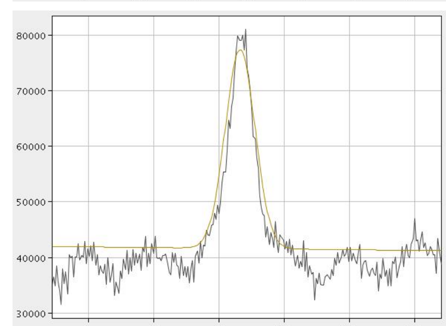




Horizontal

0.68 mm   0.70 mm





Vertical

0.56 mm   1.05 mm

Light from D3 dipole.
Blue filter. Narrow slit.

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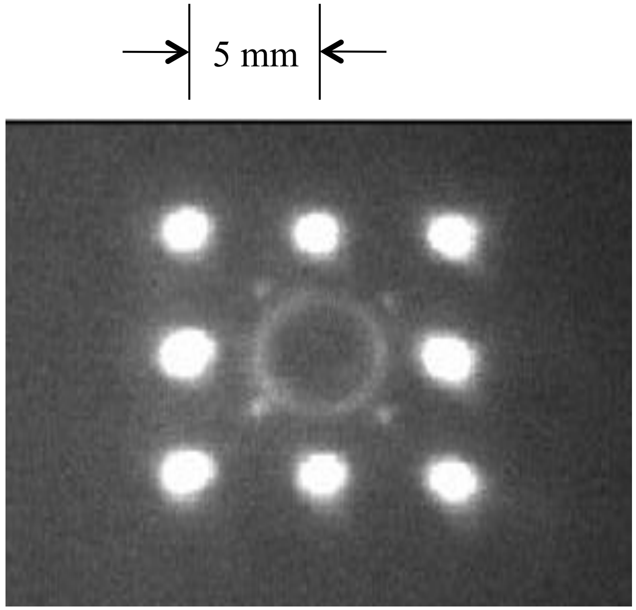
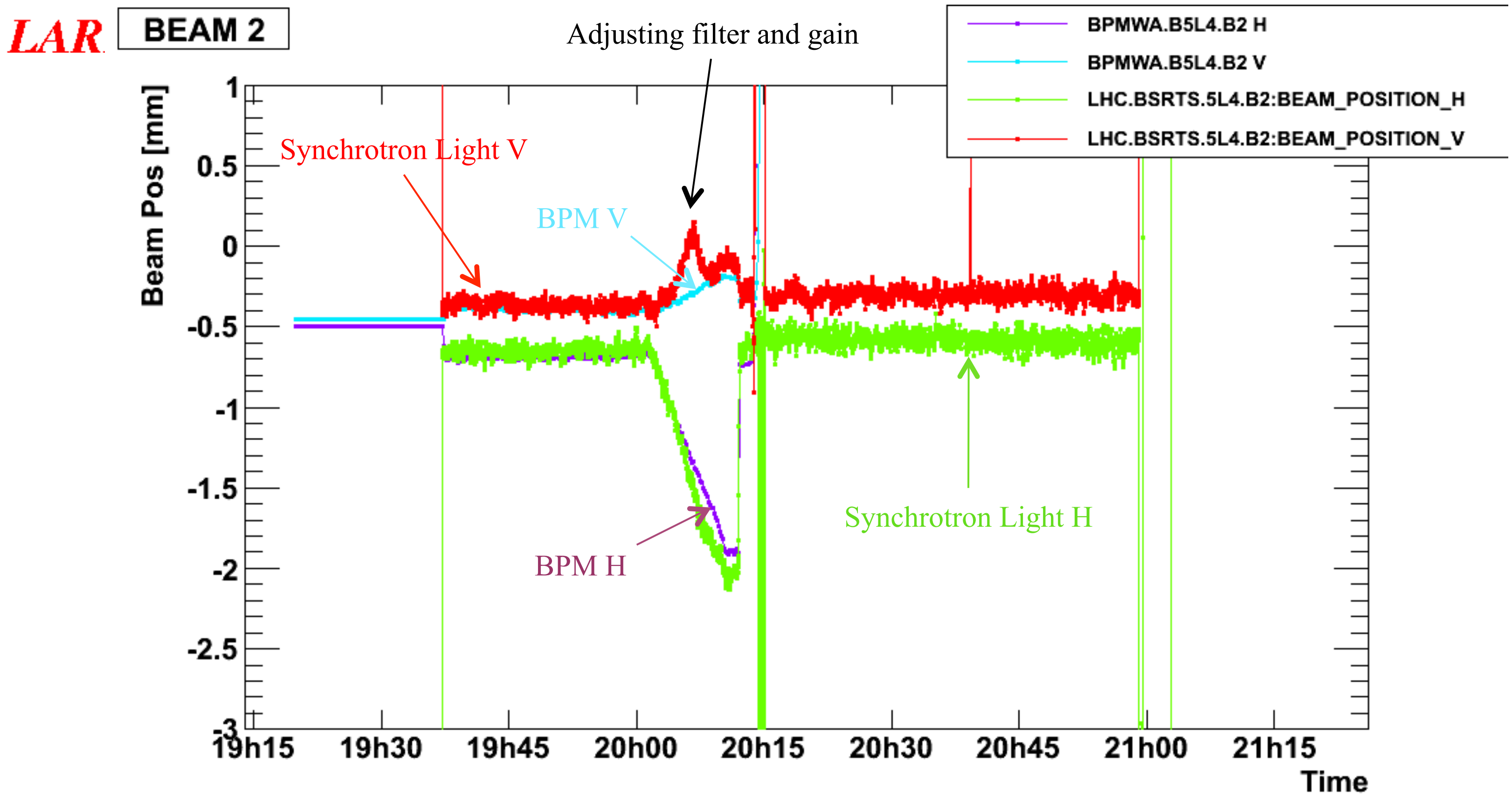
Calibration Techniques

- Target
  - Incoherently illuminated target (and alignment laser) on the optical table
  - Folded calibration path on table matches optical path of entering light
- Wire scanners
  - But adjust sizes for different $\beta_{x,y}$
  - Beam bump
  - Compare changes in image centroid and BPMs



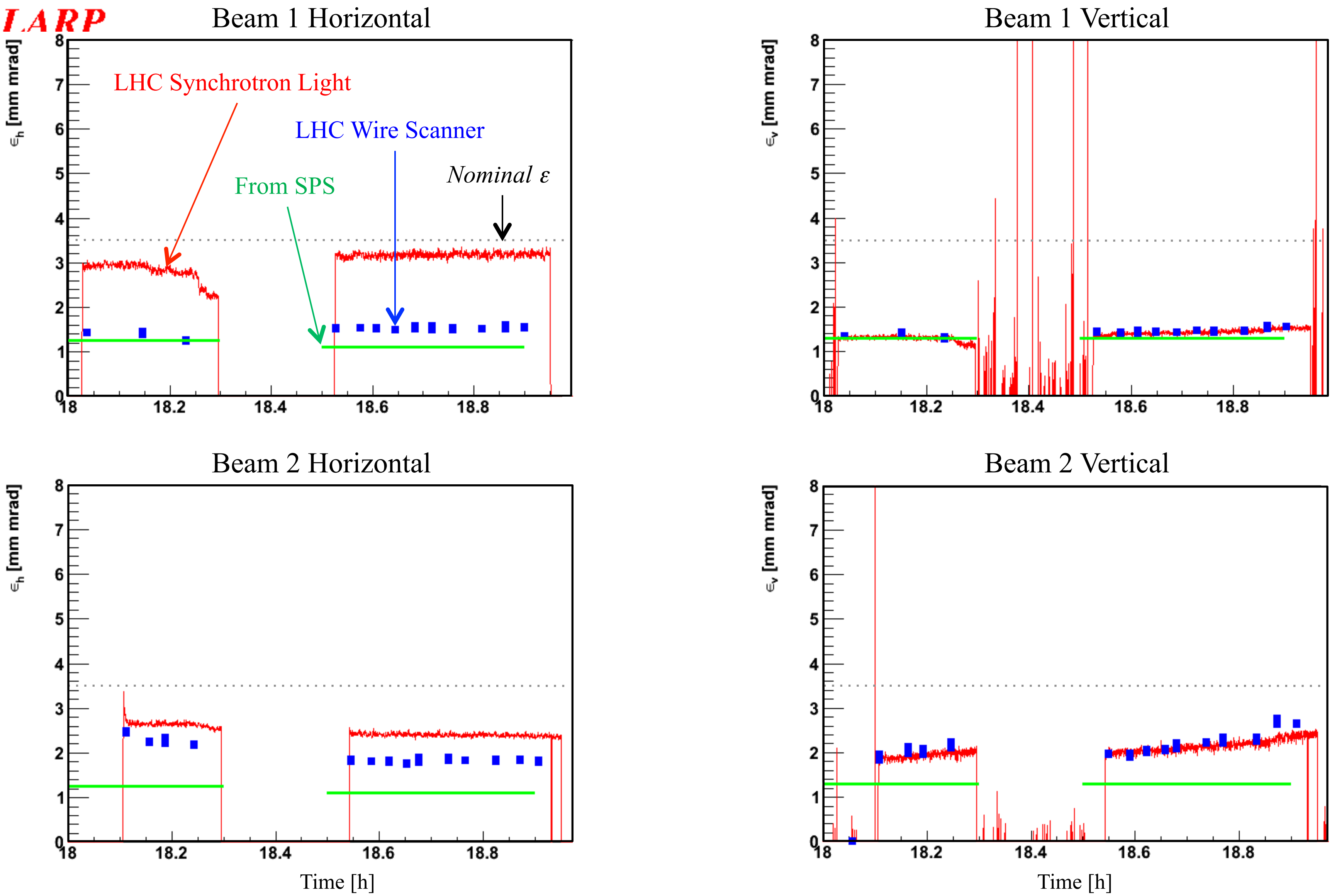
Synchrotron-Light Centroid vs. BPMs



Why do slopes during beam bump match in *x*, but not in *y*?

Why do filter and gain changes affect *x*, but not *y*?

Emittance Comparisons at 450 GeV



Some Disagreement with Wire Scanners

The horizontal size—but not the vertical—measured with synchrotron light is larger than the size from the wire scanners.

- Beam 1: Factor of 2 in *x* emittance ($\sqrt{2}$ in beam size)
- Beam 2: Factor of 1.3 in *x* emittance

β beat isn't large enough to explain this.

But image of calibration target doesn't appear distorted in *x*.

Sync Light Monitor Status

System came up extremely quickly and provides very good data

Some discrepancies are under investigation

- Cross calibrating with other instruments

Setting up duplicate system on the bench to better characterize the optics

Sync light from protons is a world's first

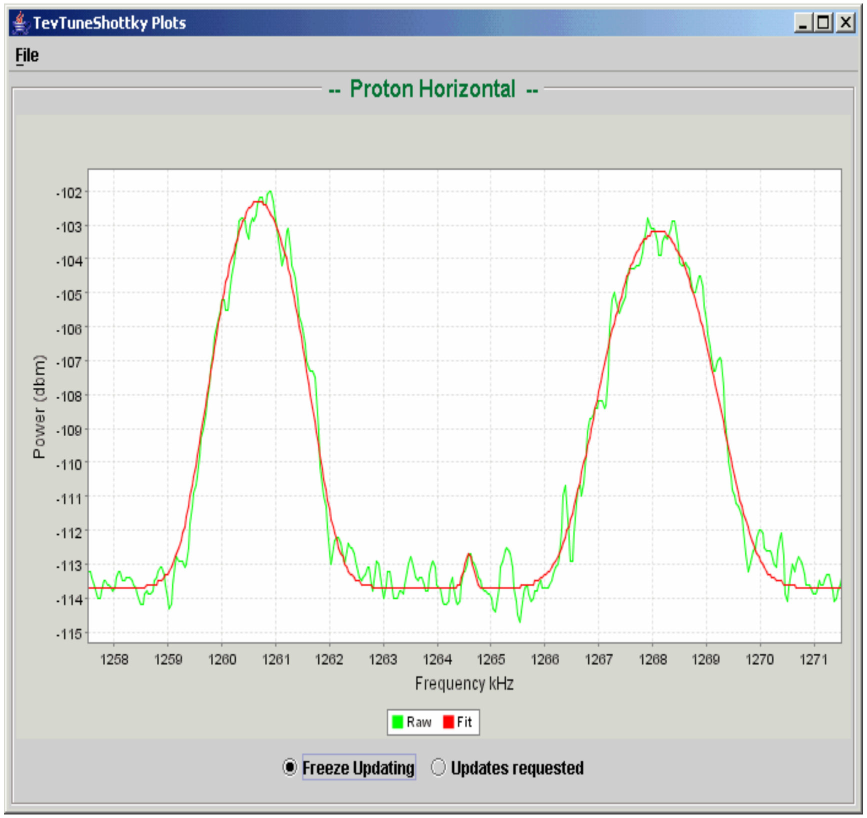
Looking forward to light from heavy ions later in this run!

Schottky Monitors

LARP

Advanced enabling technology for:

- Non invasive tune measurement for each ring from peak positions
- Non invasive chromaticity measurements from differential width
- Measure momentum spread from average width
- Continuous online emittance monitor from average band power
- Measure beam-beam tune shift



Build in capability to monitor gain variation with time

Measure individual or multiple bunches

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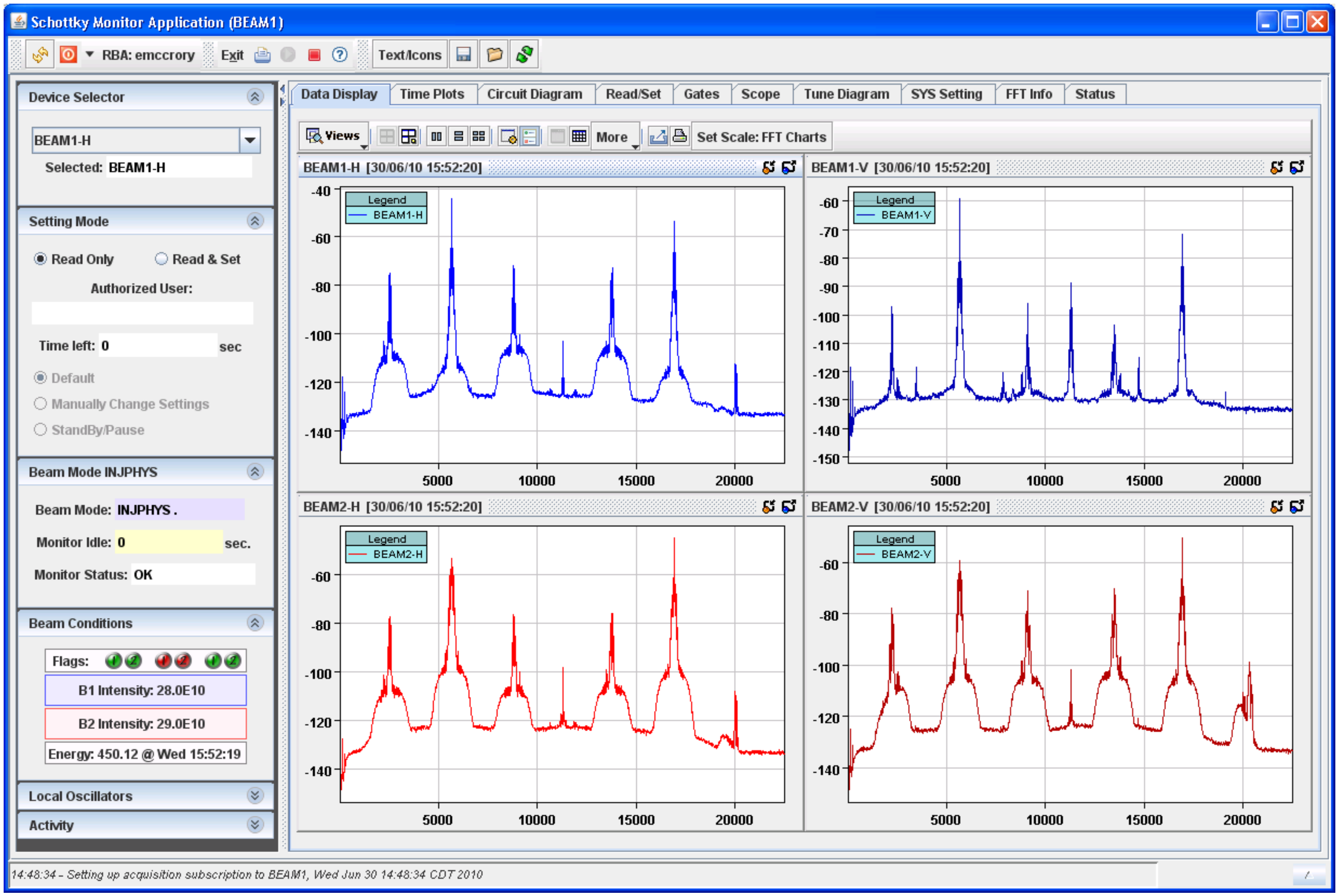
First Schottky Signals



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Schottky Monitor Status

With increased beam intensity the system is now giving good signals

Most effort currently on software interfaces and readouts thanks to LAFS collaboration

One plane needs troubleshooting

Will start using for beam measurements very soon

Tune and Coupling Feedback

Objective: Control Tune and Coupling feedback

- Develop chromaticity tracking during ramp and store

Accomplishments

- Simultaneous Tune and Coupling feedback used in RHIC run 6, **a world first**
- RHIC run 7 and 8 - Tune and Coupling feedback operational
  - focusing on chromaticity tracking

Task ended in FY07

Seeded the recent successful tune, coupling and chromaticity feedback in RHIC during the past run (BNL effort)

CERN routinely uses this system as a tune tracker during the ramps

Lumi Status

All four systems operational

- one at each side of ATLAS and CMS

Cross calibration with PMT system and ATLAS/CMS

- Very good agreement

Developing the system while the PMTs are functional

- PMTs last about 3 months at 10^{30} and about a day at 10^{31}
- Studying triggers, thresholds

Some noise pickup at Point 5 left

- seen by other instruments as well

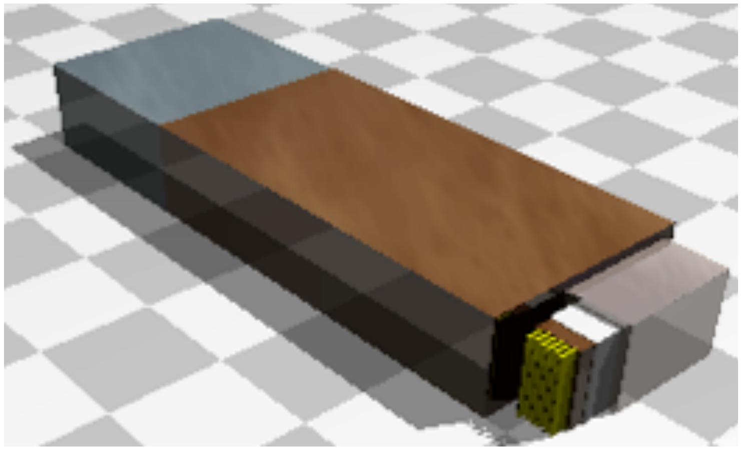
LARP

Fluka Modeling

Run at 3.5 TeV requires modeling at this energy

Using events provided by LHCf with DPMJET3

- Beam pipes between IP and TAN, and TAS located at 20 m from IP are taken into account
- Includes D1 dipole but not quadrupoles
- No fluctuations of beam energy or position



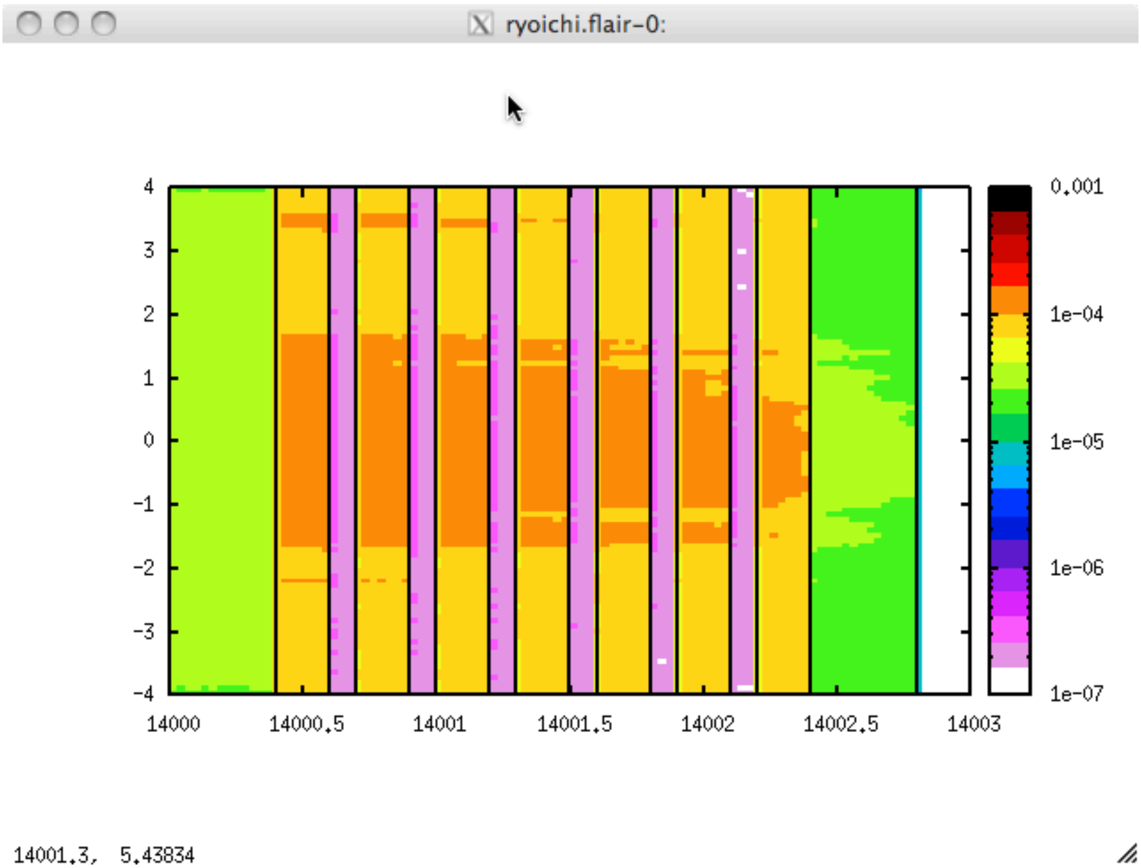
Normalized to # of pp interactions

Simplified geometry of the TAN

Study for IP5

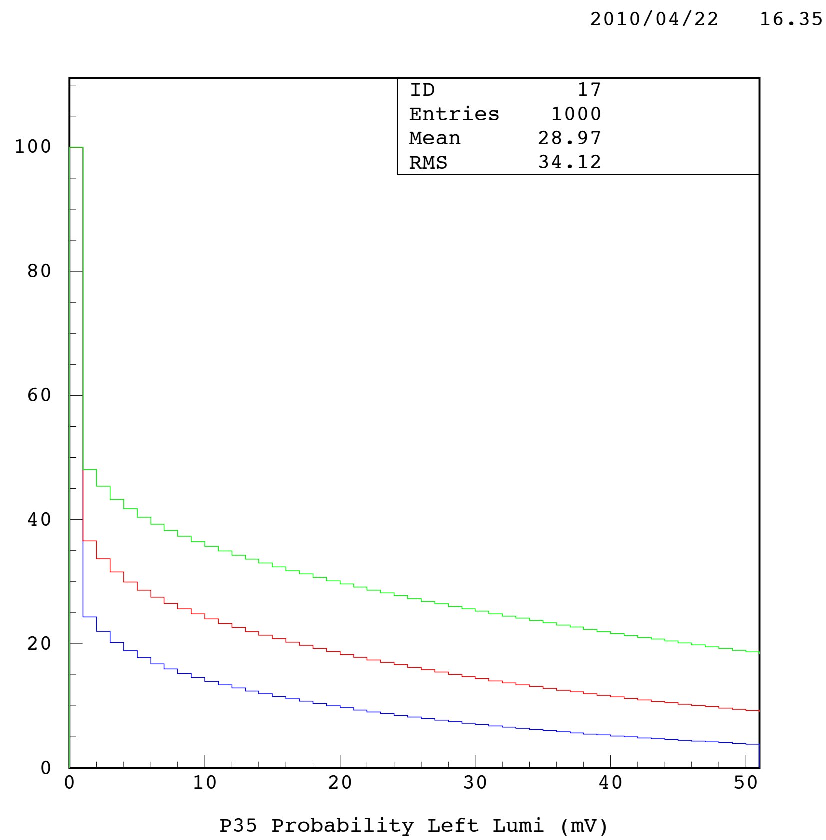
- Absorber in front of IP1 not constant due to LHCf operating mode

Energy Distribution



Chamber model
6 gaps
Copper and ceramic

Trigger probability

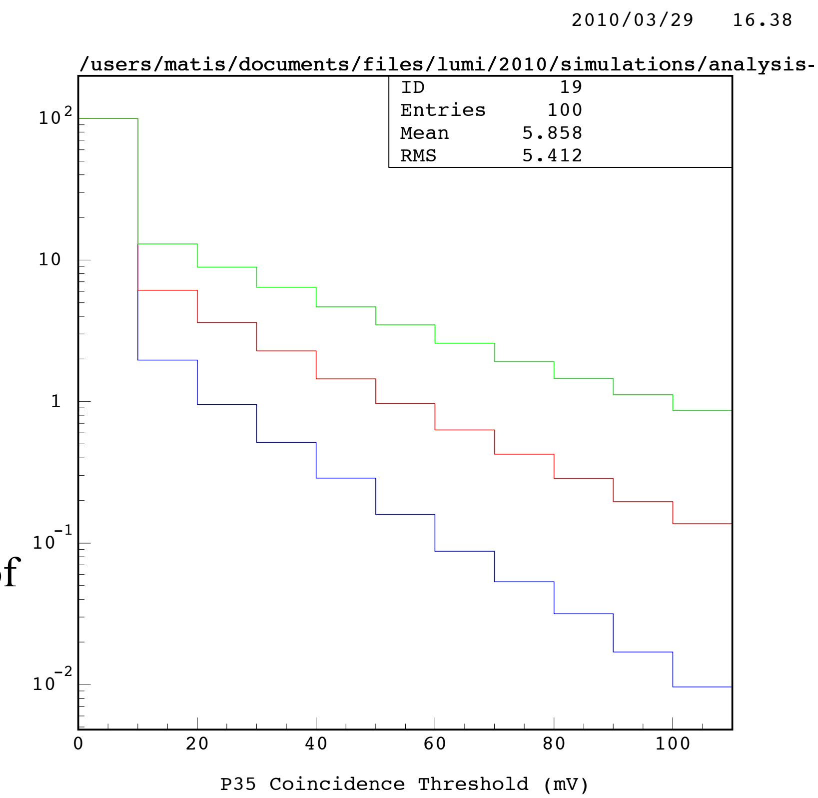


7 TeV - Green

5 TeV - Red

3.5 TeV – Blue

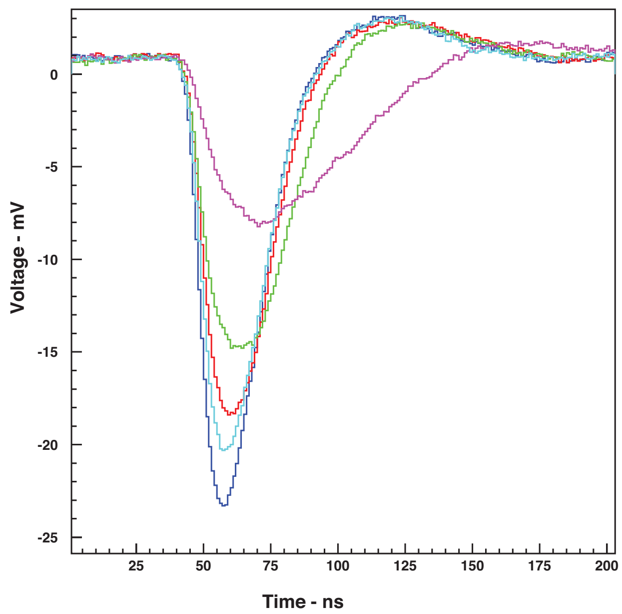
As a function of threshold



Single Events

Coincidence

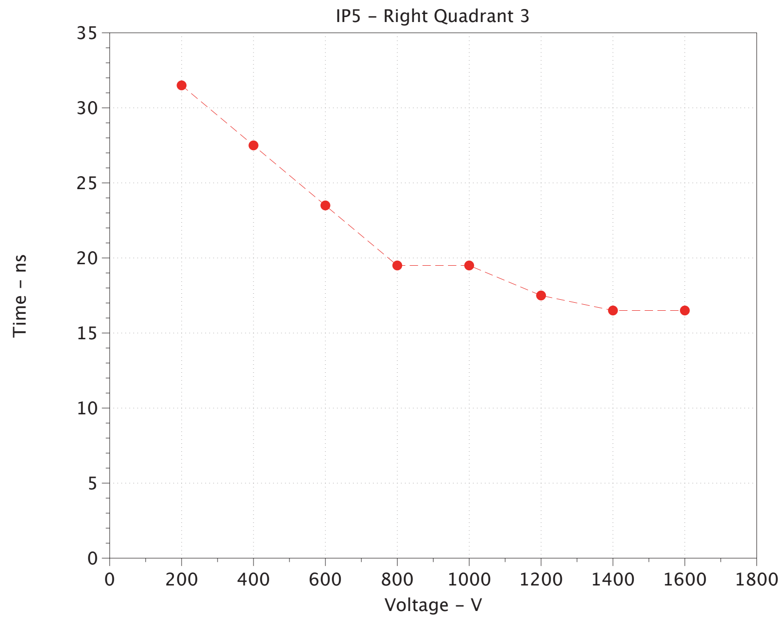
Voltage Scan



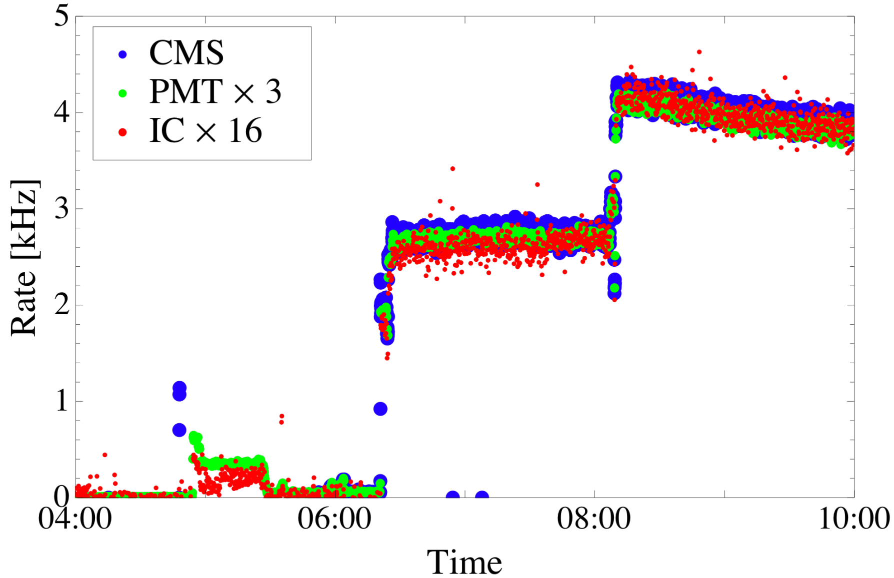
Response with bias change
In 200V steps

Peaking time as a function of bias voltage at 6 atm

200V/atm calculated optimal



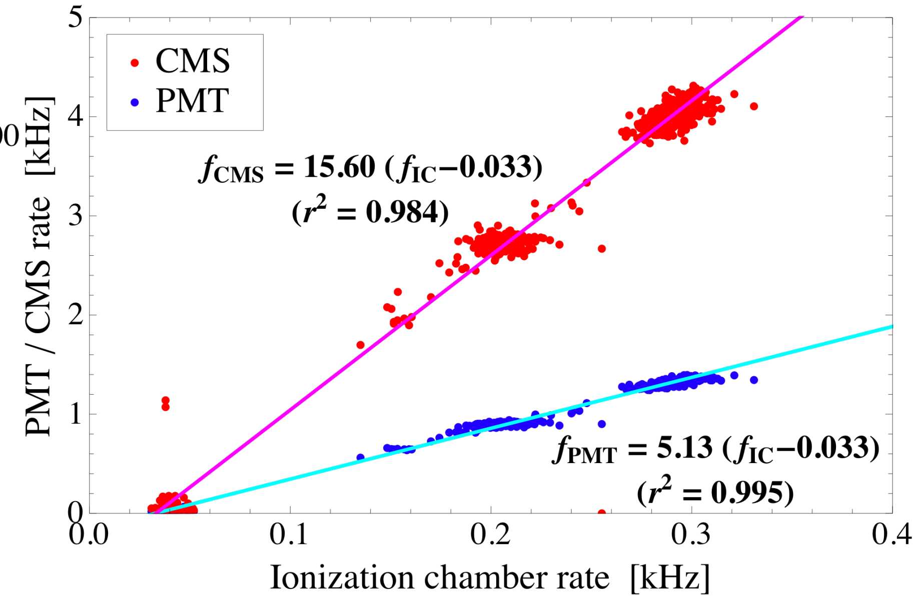
Comparison with other measurements



Vernier scan

Correlation >99%

Lumi vs. PMT and CMS



Handoff to CERN

All instruments are approaching completion

Some (AC dipole, tune tracker) are fully operational

Some (Lumi, Sync Light Monitor, Schottky) are on their way to readiness

Moving into operations requires two champions

- an instrument 'owner' in BE/BI to maintain and enhance the device
- an 'operator' in BE/OP to lead it into operations

Most of these people have been identified

- but not everyone
- Schottky Monitors in particular

Handoff to CERN (2)

Ryoichi Miyamoto – Toohig fellow – has become an essential part of LARP's success

- Local point of contact for AC dipole and Lumi
- Actively involved with optics measurements and modeling

LARP will continue to support implementation of these systems into operation, as we hand the devices off to CERN's experts

Alex and Eric to meet with CERN's POCs next week to firm up details

Collaborative Efforts

LARP works with CERN in different ways

1. LARP and CERN equally involved in the developments and implementation
   - AC Dipole – each lab built a system for own collider
   - Tune and Coupling Feedback – System developed and tested in RHIC, CERN implemented in LHC

2. LARP did studies and provided prints, CERN implemented in LHC
   - Schottky Monitor – FNAL built processing electronics modeled after the tevatron's
   - Synch Light Monitor – study by LARP, fabrication and installation by CERN

3. LARP did most of the work, CERN provided local support only
   - Luminosity Monitors

Plans for FY11

LARP

Continue development of existing instruments as the LHC performance improves

Final debugging and performance improvements

- Luminosity monitors
- Sync light monitor
- Schottky Monitors

Continue exploiting instruments to further AP studies and beam commissioning

New instrument

- Design a turn by turn profile monitor for the PS Booster
    - Collaboration between FNAL, LBNL and SLAC

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Final Considerations

Results made possible by **significant contributions** from all labs

This year we spent less than $0.5M of LARP's money

- Lumi monitor initially funded by LBL for 3 years
- AC dipole enhanced by BNL and FNAL
- Schottky monitor - controls interfaces and programming contributed by FNAL (LAFS)
- Synch Light Monitor (and LLRF) – almost entirely funded by SLAC, including one LTV

LARP management helping secure adequate resources in support of the LHC commissioning

LTVs and Toohig fellows

Integration with beam commissioning activities is essential to the success of the instruments provided by the LARP collaboration

Summary

Spending roughly $6.5M of the ~$60M spent by LARP to date, the instrumentation program has delivered tangible contributions that will help the LHC

- reach design energy
- reach design luminosity

Made possible by collaborations with CERN and contributions of each of the LARP labs

New proposals keep coming but face reducing budgets and other priorities

This program will advance the US HEP program by

- Enhancing US accelerator skills
- Developing advanced diagnostic techniques that will apply to present and future US programs
- Help maximize LHC performance